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Criticality Safety Evaluation on Generic Fissionable Materia Operations with up to 65 grams Pu-239

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Criticality Safety Evaluation

On

Generic Fissionable Material Operations With Up To 65 Grams Pu-239

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1.0 Introduction

This assessment establishes the criticality safety technical basis for generic fissionable material operations with up to 65 grams Pu-239 in various locations with all moderators and reflectors (including superior moderators and reflectors). These generic fissionable material operations are shown to be criticality safe with inadvertent criticality being incredible (or beyond extremely likely). Therefore, no controls on moderators and reflectors are required.

2.0 Description

Generic fissionable material operations with up to 65 grams Pu-239/WG Pu (Weapon Grade Pu) are permitted in any location with the following restrictions:

- Fissionable materials involved in the operations shall be isolated from fissionable materials not involved by a spacing no less than 20' (600 cm). This requirement is waivered when the fissionable materials not involved in the operations are seismically confined or anchored with a spacing no less than 16" (40 cm) away from the operations.

- Pu-239/WG Pu in the gaseous forms or under cryogenic conditions is disallowed in the generic operations.

The locations can be anywhere for these generic operations from a criticality safety perspective. It should be noted that there may be additional restrictions on the locations specified by other safety disciplines, local ordinances, and state, federal, and international regulations, which may need to be complied with as well.

3.0 Criticality Safety Methodology

The critical masses derived in CSM 936A [Heinrichs, 1998] are used to as the basis to demonstrate that the generic operations with up to 65 grams Pu-239 are criticality safe with a large safety margin. The critical masses derived in CSM 936A are based on the most reactive geometry with a spherical core of Pu-239 and CH_2 (high-density polyethylene/HDPE) and then reflected by a spherical-shell reflector made of various materials. Table 1 lists the critical masses with different reflectors. These results are extracted from Table III of CSM 936A.

Table 1. Pu-239 Critical Masses for various reflectors

Reflector	Density (g/cc)	Critical Mass (g)*
None	-	535
Water (H_2O)	1.0	320
Ch_2 (high-density polyethylene/HDPE)	0.961	300
Natural Uranium (Nat-U)	19.07	220
Graphite/Carbon (C)	2.25	205
Lead (Pb)	11.3437	200
Beryllium (Be)	1.85	150

* The critical mass is derived is based on a Pu-CH_2 core with the optimized moderation (65 g Pu-239/L with H/Pu-239=872). CH_2 density is 0.961 g/cc. However, the critical mass is not applicable to cases with Pu-239 in the gaseous form or under cryogenic conditions.

It is shown in Table 1 that the most effective reflector is beryllium, which yields in the smallest critical mass. Superior reflectors (to water), such as HDPE, Nat-U, C and Pb are not as effective compared to Be because of larger critical masses.

It should also be noted that HDPE is the most effective moderator because of its high hydrogen atom concentration. Therefore, Pu-239 systems optimally moderated by HDPE and reflected by Be bound all other Pu-239 systems optically moderated by other moderators and reflected by other reflectors.

4.0 Normal Operation and Credible Upset Scenarios and Bounding Scenarios

Normal operation and credible upset conditions are considered in this assessment. To simplify the assessment, bounding normal operation and credible upset scenarios are used.

4.1 Normal Operation Scenario:

The normal operation scenario for the generic operations is 65 grams Pu-239 optimally moderated by moderator and fully reflected by reflector. From Table 1, it is deduced that the most reactive configuration is reflected by beryllium. Therefore, for this assessment, the bounding normal operation scenario involves 65 grams Pu-239 optimally moderated by HDPE and fully reflected by beryllium (Be).

4.2 Credible upset scenarios:

4.2.1 Fissile Double Batch

Fissile Double Batch with Pu-239 involved being 130 grams, rather than 65 grams, with optimized moderation by moderators and reflected by reflectors. The bounding fissile double batch scenario is then 130 grams Pu-239 with optimized HDPE moderation and full Be reflection.

4.2.2 Loss of Configuration Control (Spacing) Control

Loss of Spacing controls involve 65 grams Pu-239 being placed next to 65 grams Pu-239, resulting a total of 130 grams Pu-239. The bounding loss of configuration control scenario is then 130 grams Pu-239 with optimized HDPE moderation and full Be reflection. This bounding loss of configuration control scenario is the same as the bounding scenario described in 4.2.1 for the bounding fissile double batch scenario.

To preserve the assumptions related to the bounding loss of configuration control scenario, fissionable materials not involved in the proposed operations but in their vicinity need to be seismically confined or anchored to prevent these fissionable materials from being moved into the proposed operations in the event of earthquakes.

4.2.3 Moderator and Reflector Over Masses

Moderator Over Mass results in deviation from the optimized moderation causing reactivity decreases and reflector over mass results in deviation from full Be reflection, which can reduce the effectiveness in neutron reflection. In this regard, moderator and reflector over masses are bounded by the bounding normal operation scenario with 65 grams Pu-239 with optimized HDPE moderation and full Be reflection as discussed in Section 4.1.

4.2.4 Flooding

Flooding with 65 grams Pu-239 optimally moderated by moderator and fully reflected by reflector. Presence of water will reduce the effectiveness of HDPE moderation and Be reflection. Therefore, the flooding scenario is bounded by 65 grams Pu-239 with optimized HDPE moderation and Be reflection, which is identical to the bounding normal operation scenario as discussed in Section 4.1.

4.2.5 Fire/Firewater

Fire with 65 grams Pu-239 optimally moderated by moderator and fully reflected by reflector. Water moderation and reflection are not as effective compared to HDPE moderation and Be reflection. Therefore, the bounding flooding scenario involves 65 grams Pu-239 with optimized HDPE moderation and Be reflection, which is the same as the bounding normal operation scenarios as discussed in Section 4.1.

4.2.6 Earthquake

Earth quakes may results in the collapse of surrounding structures into 65 grams Pu-239 and the breaking of water pipes. This can result in water moderation and water and structure debris reflection. Water is not as effective a moderator compared to HDPE. Furthermore, water and structure debris are not as effective moderators compared to Be. Therefore, the bounding earth quake scenario is 65 grams Pu-239 with optimized HDPE moderation and full Be reflection, which is the same as the bounding normal operation scenarios as discussed in Section 4.1.

To preserve the assumptions related to the earthquake scenario, fissionable materials not involved in the proposed operations but in their vicinity need to be seismically confined or anchored to prevent these fissionable materials from being moved into the proposed operations in the event of earthquakes.

4.2.7 Strong Wind

For operations in open spaces, the strong wind can disperse 65 grams Pu-239 involved in the operations. Dispersion of Pu-239 can result in radioactive contaminations but dilute Pu-239 to beyond criticality concern. For operations near structures or indoors, strong winds may cause the surrounding structure to collapse as well as the breaking of embedded water pipes. This again can result in water moderation and water and structure debris reflection. Water is not as effective a moderator compared to HDPE. Furthermore, water and structure debris are not as effective reflectors compared to Be. Therefore, the bounding strong wind scenario is 65 grams Pu-239 with optimized HDPE moderation and full Be reflection, which is the same as the bounding normal operation scenarios as discussed in Section 4.1.

4.2.8 Dropping/Spilling

When dropping or spilling 65 grams Pu-239, there may be changes in the shape and the may be additional reflection from the ground. This dropping/spilling scenario can result in change shapes to less reactive configuration. The ground reflection will not be as effective as the beryllium reflection. In this regard, the bounding dropping/spilling scenario remains 65 grams Pu-239 in the most reactive geometry with optimized HDPE moderation and full Be reflection, which is the same as the bounding normal operation scenarios as discussed in Section 4.1.

4.3 Bounding Scenarios

Based on the discussions in Sections 4.1 and 4.2, the normal operation and credible upset scenarios are bounded by two bounding scenarios. Table 2 shows the two bounding scenarios and the normal operation and credible upset scenarios they bound:

Table 2 Bounding Scenarios and the normal operation and credible upset scenarios bounded.

Bounding Scenario	Description	Normal Operation and Credible Upset Scenario Bounded
1	65 grams Pu-239 with optimized HDPE moderation and full Be reflection	Normal operation scenario (Section 4.1) Moderator and Reflector Over Masses (Section 4.2.3) Flooding (Section 4.2.4) Fire/Firewater (Section 4.2.5) Earthquake (Section 4.2.6) Strong Wind (Section 4.2.7) Dropping/Spilling (Section 4.2.8)
2	130 grams Pu-239 with optimized HDPE moderation and full Be reflection	Fissile Over Mass (Section 4.2.1) Loss of Configuration Control/Spacing (Section 4.2.2)

5.0 Criticality Safety Analysis

The two bounding scenarios summarized in Table 2 are analyzed here.

Bounding Scenario 1: 65 grams Pu-239 with optimized HDPE moderation and full Be reflection

Bounding Scenario 1 involves 65 grams Pu-239 with optimized HDPE moderation and full Be reflection. It is shown in Table 1 that the critical mass is 150 grams Pu-239 with optimized HDPE reflection and full Be reflection. 65 grams Pu-239 are 43.3% of the critical mass. Since 65 grams Pu-239 are less than a critical mass, Bounding Scenario 1 is subcritical and criticality safe.

Bounding Scenario 2: 130 grams Pu-239 with optimized HDPE moderation and full Be reflection

Bounding Scenario 2 involves 130 grams Pu-239 with optimized HDPE moderation and full Be reflection. It is shown in Table 1 that the critical mass is 150 grams Pu-239 with optimized HDPE reflection and full Be reflection. 130 grams Pu-239 are 86.7% of the critical mass. Since 130 grams Pu-239 are less than a critical mass, Bounding Scenario 2 is subcritical and criticality safe.

Table 3. Bounding Scenarios in critical mass (CM) for generic 65-gram Pu-239 operations

Bounding Scenario	Description	Critical Mass (CM)	Events Bounded
1	65 grams Pu-239 with optimized HDPE moderation and full Be reflection	43.3% CM	Normal operation scenario (Section 4.1) Moderator and Reflector Over Masses (Section 4.2.3) Flooding (Section 4.2.4) Fire/Firewater (Section 4.2.5) Earthquake (Section 4.2.6) Strong Wind (Section 4.2.7) Dropping/Spilling (Section 4.2.8)
2	130 grams Pu-239 with optimized HDPE moderation and full Be reflection	86.7% CM	Fissile Over Mass (Section 4.2.1) Loss of Configuration Control/Spacing (Section 4.2.2)

6.0 DESIGN FEATURES AND ADMINISTRATIVE CONTROLS

These criticality safety controls for the proposed generic Pu-239 operations are as follows:

- Fissionable material operations shall be limited to no more than 65 grams Pu-239.
- Fissionable materials involved in the operations shall be isolated from fissionable materials not involved by a spacing no less than 20' (600 cm). This requirement is waivered when the fissionable materials not involved in the operations are seismically confined or anchored with a spacing no less than 16" away from the operations.
- Fissionable material operations with Pu-239/WG Pu (Weapon-Grade Pu) in the gaseous form or under cryogenic conditions are disallowed. Deviations from these requirements need further criticality safety review on a case-by-case basis prior to implementation.

7.0 CRITICALITY HAZARD TYPE

The Criticality Hazard Type of 1 is assigned to the generic 65-gram Pu-239 fissionable material operations. ***Fire Fighting Guidance:*** In the event of fire, water may be used.

8.0 CRITICALITY BARRIERS

The available criticality barriers for the generic 65-gram Pu fissionable material operations are listed in Table 4:

Table 4. List of available criticality safety barriers for generic 65-gram Pu-239 operations

Barrier Parameters	Barriers Formally Claimed (BFC; yes=1; no=0)	Remarks
Neutronic Coupling	1	16" (40-cm) Isolation or 20' (600 cm) not seismically qualified
Poison	0	Not Used
Density	1	Pu-239 @ full density
Reflection (Albedo)	1	Superior Reflector Safe; Full Reflection Safe
Shape (Geometry)	1	Optimized Spherical geometry
Volume	0	Not Used
Material Form	0	Not Used
Concentration	0	Not used
Enrichment/Fissile Composition	1	100% Pu-239 for WG Pu
Moderation	1	Superior Moderator Safe Optimized Moderation
Mass	1	Inventory and Mass Limits
Sum:	BFC=7	

9.0 CONCLUSIONS

When Pu-239 is not in the gaseous form or under cryogenic conditions, fissionable material operations with up to 65 grams are bounded by the most strict operation mass limit (with Be reflection). Therefore, no criticality safety control on the amount of any moderator or reflector is needed. In other words, other than in the gaseous form or under the cryogenic conditions (or in the vicinity, 16" or less seismically qualified or 20' or less not seismically qualified, of these conditions or other fissionable materials), up to 65 grams Pu-239/WG Pu can be in any form, in any condition, in any configuration, and in any location with all moderators and reflectors. These fissionable material operations are double-batch safe with a large safety margin. Furthermore, they are criticality safe with inadvertent criticality being incredible (beyond extremely unlikely). In this regard, the generic fissionable material operations with up to 65 grams Pu-239/WG Pu meet (in reality, exceed) the Double-Contingency Principle on criticality safety as mandated by DOE Order 420.1B.

In the event of fire, water can be used for the generic operations with 65 grams Pu-239.

10.0 REFERENCES

Dave Heinrichs, U-233, Pu-239 and Pu-239 Minimum Critical Masses (High-Density Polyethylene Moderation with Various Reflector Materials, CSM 936A), February 1998.